

MSC-01264



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 69-FM-318

December 24, 1969

EARTH LAUNCH WINDOW ANALYSIS
OF THE 1986 MARS CONJUNCTION
CLASS MISSION

(NASA-TM-X-69734) EARTH LAUNCH WINDOW
ANALYSIS OF THE 1986 (NASA) 41 p

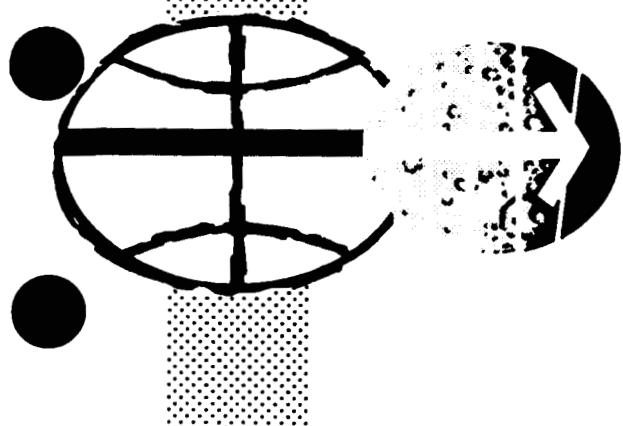
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Advanced Mission Design Branch

MISSION PLANNING AND ANALYSIS DIVISION

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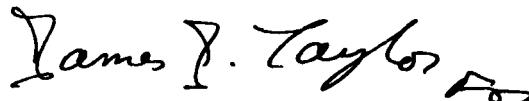
EARTH LAUNCH WINDOW ANALYSIS OF THE 1986
MARS CONJUNCTION CLASS MISSION

By Charles W. Arvey and John T. McNeely
Advanced Mission Design Branch

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MISSION PLANNING AND ANALYSIS DIVISION
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By Charles W. Arvey and John T. McNeely

1.0 SUMMARY

An Earth launch window analysis of the 1986 Mars conjunction class mission is presented. Four different sets of Earth departure V_{∞} vectors (four energy windows) are considered to provide the best evaluation of the ΔV requirements of the mission. The effects of both circular and elliptical assembly parking orbits of initially equal orbital energies are considered as well as the effect of orbit inclination. The five circular assembly orbits used in this report exhibit the same groundtrack approximately every 24 hours; and, for three of these orbits, two direct rendezvous per day are possible after launch from Cape Kennedy. The elliptical assembly orbits offer a more efficient conversion of propulsive energy to orbital energy during the Earth departure maneuver; thus, lower ΔV 's are required. The departure ΔV requirement was minimized in the region of the departure date which gave the lowest sum of Mars orbit insertion ΔV and transearth injection ΔV , and these favorable departure windows are presented.

2.0 INTRODUCTION

Assembly of the main spacecraft and the orbital launch vehicles (OLV) in Earth orbit is required for a manned interplanetary mission to Mars. Several weeks are required to launch the assortment of vehicles, to assemble these vehicles in Earth orbit, and to check out the spacecraft. Reorientation (change in the inclination or the longitude of the ascending node) of the assembly orbit after any or all of the stages have been launched is very costly in terms of trans-Mars payload. For this reason, the initial orientation of the assembly orbit should be chosen to minimize the plane change requirement and to maximize the number of days during which Earth orbit departure is possible with a given orbital launch vehicle capability.

Maximization of the Earth orbital departure window for the 1986 Mars conjunction class mission is analyzed in this report by use of the multiple orbit injection technique and the orbital launch window analysis program discussed in references 1 and 2. The main parameter of variation is the initial data of launch from the Cape, although a variation in orbit inclination is considered. The use of both circular and elliptical assembly parking orbits is investigated. The orbital departure window for each mission was maximized in the region for which spacecraft ΔV requirements at Mars are minimum.

The basic input to the orbital launch window analysis program is a set of Earth departure V_∞ vectors for the time span of interest. Three such sets of V_∞ vectors were obtained from reference 3. These three data sets include the following: two-impulse type I (Earth-to-Mars transfer angles less than 180°) trans-Mars trajectories, three-impulse trans-Mars trajectories with Earth departure asymptotes constrained to be in the ecliptic plane, and three-impulse trans-Mars trajectories with Mars arrival asymptotes constrained to be in the Mars orbit plane. A fourth data set that is composed of Earth departure V_∞ vectors for two-impulse type 2 (Earth-to-Mars transfer angles greater than 180°) trans-Mars trajectories was obtained from reference 4. All four data sets are composed of missions which require the minimum total ΔV for the constraints imposed and are listed in the appendix of this report. A similiar launch window analysis study of the 1981 Mars stopover/Venus inbound swingby mission is presented in reference 5.

3.0 SYMBOLS

G.m.t.	Greenwich mean time
Δt	time relative to final impulse, hr
h_a	altitude of apogee, n. mi.
h_p	altitude of perigee, n. mi.
i	inclination of orbit, deg
Ω	right ascension of ascending node, deg
ω	argument of periapsis, deg
V_∞	magnitude of \vec{V}_∞ , fps

ΔV_E	total Earth departure ΔV , fps
ΔV_M	sum of velocity requirements at Mars (MOI + TEI), fps
MOI	Mars orbit insertion
TEI	transearth injection
OLV	orbital launch vehicle

4.0 ANALYSIS

The orbital departure technique used in this report to determine the effective orbital departure windows is schematically illustrated in figure 1. The first three thrusting maneuvers increase the apoapsis altitude of the spacecraft's orbit. The position of periapsis remains fixed except for the alinement of the orbit plane and line of apsides which change because of the oblateness of the Earth. The fourth maneuver is the most important factor in the determination of the orbital launch window because it is directly influenced by the plane change requirement. This maneuver is made near apoapsis (approximately 65 000-n. mi. altitude) and rotates the orbit plane so that it contains the departure asymptote. Because the longitude of the ascending node regresses at approximately 7° per day, because the line of apsides precesses, and because the latitude and longitude of the departure asymptote shift, the orbit plane change requirement can vary quite rapidly. The fifth maneuver occurs at periapsis and given the vehicle the energy required to attain the proper hyperbolic excess velocity.

Although three intermediate orbits are used in this multiorbit injection analysis, the optimum number of orbits depends upon several tradeoff parameters that involve performance characteristics and operational procedures. Increasing the number of intermediate orbits affects the magnitude of the propulsion losses but has only a minor effect on the shape of the departure window. The propulsion losses used in this analysis are based on a six-orbit departure sequence which is more nearly optimum than the three-orbit sequence used here (with the propulsion losses adjusted for a six-orbit sequence) for convenience of computation.

The way in which the plane change requirement affects the total departure ΔV requirement is shown in figure 2 for a typical interplanetary departure. The bottom curve represents the impulsive coplanar ΔV requirement and reflects the variation in the magnitude of the Earth departure V_∞ vector. The middle curve shows the effect of propulsion

losses such as gravity losses and cooldown propellant losses in the case of a nuclear engine. These losses are approximately 850 fps for this study. The upper curve shows the effect of the plane change requirement which is determined by the relative positions of the ascending node of the parking orbit and the departure asymptote. This curve represents the envelope of minimum ΔV requirements for each orbit and, therefore, is not continuous. However, approximately 16 departure opportunities per day are possible for parking orbits of the type discussed in this report; therefore, the curve will be considered continuous and will be referred to as the orbital departure window curve. In the case of the circular parking orbit, the upper curve touches the middle curve at several points. These points correspond to a zero plane change requirement. That is, the orbit plane is correctly aligned to contain the departure asymptote. This alignment results in the lowest possible departure ΔV for that departure date. In the case of the elliptical parking orbit, the orbital departure window curve can touch the middle curve only if the orbit plane contains the departure asymptote and the line of apsides is in the proper position to permit a departure from periapsis. Normally, this situation will not occur more than once per departure window. That portion of the departure window curve which is beneath a given OLV capability will be referred to as the orbital departure window.

Five circular assembly orbits were investigated in this report and are listed along with related data in table I. Three of the assembly orbits have the characteristic that two direct rendezvous from Cape Kennedy are possible every 15 revolutions (approximately 24 hours) for both east launch azimuth quadrants. That is, one launch would have a northeast launch azimuth and the other would have a southeast launch azimuth. The three orbit inclinations are 29.16° , 31.08° , and 34.70° , and a southeast launch opportunity follows a northeast launch opportunity by one, two, and three revolutions, respectively. The corresponding orbit altitudes are 260.33 n. mi., 260.83 n. mi., and 261.87 n. mi. The other two circular assembly orbits have inclinations of 45° and 55° and orbit altitudes of 266 n. mi. and 271 n. mi., respectively. One direct rendezvous from Cape Kennedy is possible every 15 revolutions for these two orbits which were considered because they reduce the plane change requirement of those missions with high declination departure asymptotes. However, launch azimuth constraints at Cape Kennedy are not considered. An elliptical assembly orbit was also considered for comparison purposes although it cannot provide the rendezvous compatibility of the type described for the circular assembly orbit. However, the elliptical orbit, which is 100 by 427.36 n. mi. and of equal initial orbital energy as the 260.33-n. mi. circular orbit, is a more efficient orbit from which to depart Earth. Lowering the initial perigee altitude for the departure sequence from 260 n. mi. to 100 n. mi. results in a total ΔV savings of approximately 370 fps.

When assembly orbit inclination and altitude are specified, the only parameter of variation is pad lift-off time. Earth departure ΔV is shown in figure 3 as a function of orbital departure date and initial pad lift-off time. There is a 0.1-day variation in initial launch time between each of the three curves. Note that initial pad lift-off time greatly influences the orbital departure window placement and departure ΔV requirement. These curves retrace themselves every 23.49 hours in the case of the 29.16° inclination orbit used in this report; therefore, if a launch opportunity is missed, another opportunity exists after a 1-day hold.

Four sets of Earth departure V_∞ vectors are considered in this report to adequately determine the ΔV requirements for the 1986 Mars conjunction class mission. For convenience of discussion, these data sets will be referred to as sets 1, 2, 3, and 4 and are defined as follows.

- a. Set 1: two-impulse trans-Mars trajectories with transfer angles of less than 180° and unconstrained departure/arrival asymptotes
- b. Set 2: three-impulse trans-Mars trajectories with Earth departure asymptotes constrained to be in the ecliptic plane
- c. Set 3: three-impulse trans-Mars trajectories with Mars arrival asymptotes constrained to be in the Mars orbit plane
- d. Set 4: two-impulse trans-Mars trajectories with transfer angles of greater than 180° and unconstrained departure/arrival asymptotes

Because the data in sets 1 and 4 overlap somewhat as do the data in sets 2 and 3, the best portions of each set could have been combined to form wider and lower impulsive ΔV energy windows. However, when the Earth departure sequence is initiated from a fixed orbit and plane change requirements are considered, the orbital departure window curve becomes discontinuous and difficult to evaluate. For this reason, all data sets were considered separately.

5.0 RESULTS AND DISCUSSION

A primary consideration in obtaining the orbital departure window curves was the spacecraft ΔV requirements at Mars: Mars orbit insertion (MOI) ΔV and transearth injection (TEI) ΔV . All departure windows were quasi-optimized in the regions of the orbital departure date which gave the lowest sum of the MOI and TEI ΔV 's. A full optimization requires the specification of the maximum OLV and spacecraft ΔV capabilities which were not determined at the time of this study. The ΔV requirements

and quasi-optimum orbital departure windows for the 1986 Mars conjunction class mission are shown in figures 4 through 7 for circular parking orbits at Earth and data sets 1 through 4, respectively. Corresponding data for a 100-by 427.36-n. mi. elliptical parking orbit at Earth are shown in figures 8 through 11. Earth departure asymptotes with relatively high declinations (greater than 40°) are present in data sets 1 and 3. These asymptotes cause a considerable ΔV penalty when 30° inclination parking orbits are used. This is readily seen in figures 4, 6, 8, and 10. Parking orbit inclinations up to 55° are considered to permit coplanar departure maneuvers. These higher inclination orbits necessarily increase the required ΔV capability of the pad launch vehicle. The ΔV 's required for MOI and TEI were calculated assuming a coplanar impulsive maneuver at periapsis of a 200-by 10 000-n. mi. orbit at Mars. The accuracy of this assumption can be seen from the discussion of reference 4.

The diagonally hatched vertical section in figures 7 and 11 results because the heliocentric phases of the missions represented are close to 180° transfers, and a two-impulse trajectory model as used in reference 4 is inadequate for mission optimization. Multiple impulse heliocentric transfers are required in these regions.

For a 260.33-n. mi. altitude circular assembly orbit with a 29.16° inclination, as assumed OLV capability of 13 500 fps, and with consideration given only to that portion of the energy window which gives the lowest ΔV requirements at Mars, Earth orbital departure windows of 9 days, 26.5 days, 12.5 days, and 17 days are possible for the four data sets, respectively. Using the elliptical parking orbit increases these departure windows to 11.5 days, 28 days, 15 days, and 18.5 days, respectively. Use of a higher inclination parking orbit for data sets 1 and 3 widens the departure window significantly (figs. 4, 6, 8, and 10). Data set 1 offers the lowest ΔV requirements at Mars and sets 2 and 4 require the highest.

Two-launch schedules are summarized in table II for each of the four mission data sets; one for the circular parking orbit and one for the elliptical parking orbit. The orbital characteristics of the initial and final orbits of the departure sequence are given for specific times. The initial data of launch from Cape Kennedy is not given in table II, but the possibilities are indicated in figures 12 through 15 for the four data sets and the circular parking orbit with a 29.16° inclination and 260.33-n. mi. altitude. For this parking orbit, a southeast launch opportunity occurs 1.66 hours after a northeast launch opportunity. The solid and dashed lines are trend lines because only two launches are possible every 23.49 hours. If no limitation is placed on the time of day of launch from Cape Kennedy, the first vehicle and all subsequent vehicles can be launched at any time indicated by either trend line (twice every 24 hr). A launch at any time not indicated by either trend line would result in a ΔV penalty to achieve the specified orbital departure window.

6.0 CONCLUSIONS

Of the four 1986 Mars conjunction class mission energy windows presented in this report, data set 1 (two-impulse trans-Mars trajectories with transfer angles of less than 180°) requires the lowest sum of the MOI ΔV and TEI ΔV ; and data set 2 (three-impulse trans-Mars trajectories with Earth departure asymptotes in the ecliptic plane) and data set 4 (two-impulse trans-Mars trajectories with transfer angles of greater than 180°) require the highest ΔV . The MOI and TEI ΔV requirements for data set 3 (three-impulse trans-Mars trajectories with Mars arrival asymptotes in the Mars orbit plane) are between the requirements of sets 1 and 2 which are, respectively, less than 9000 fps and more than 10 000 fps. Data sets 1, 2, and 3 have approximately the same basic Earth departure energy requirements. However, the Earth departure asymptotes in data sets 1 and 3 have relatively high declinations, and orbit inclinations higher than 30° are required to achieve the wider orbital departure windows. When the spacecraft is assembled and parked in a 260.33-n. mi. circular orbit with a 29.16° inclination and the orbital launch vehicle capability is 13 500 fps, departure windows of 9 days, 26.5 days, 12.5 days, and 17 days are possible for the four energy windows, respectively. Use of a 100-by 427.36-n. mi. elliptical parking orbit with a 29.16° inclination increases these departure windows to 11.5 days, 28 days, 15 days, and 18.5 days, respectively. Significantly larger departure windows are possible for data sets 1 and 3 when parking orbits with inclinations higher than 30° are used. Considering spacecraft ΔV requirements at Mars and the penalties associated with high inclination parking orbits at Earth, data set 2 contains the most favorable Earth departure V_∞ vectors (i.e., three-impulse trans-Mars trajectories with Earth departure asymptotes in the ecliptic plane).

TABLE I.- CIRCULAR ASSEMBLY ORBIT PARAMETERS

Inclination, deg	Altitude, n. mi.	Launch azimuth, deg		Launch interval, hr	
		Northeast	Southeast	δt^a	Δt^b
^c 29.16	260.33	83.12	97.51	1.66	23.49
^c 31.08	260.83	75.36	105.28	3.33	23.50
^c 34.70	261.87	66.33	114.30	4.99	23.52
45.00	266.00	48.23	132.39	--	23.56
55.00	271.00	33.80	146.81	--	23.60

^aBetween the northeast and southeast launch opportunities.

^bBetween launches on a given azimuth.

^cPhases for twice-a-day standard rendezvous.

TABLE II.- SUMMARY OF DEPARTURE SEQUENCES

(a) Assembly orbit (just prior to injection sequence)

V_∞ data case no.	Time, month/day/hour G.m.t. ^a	Δt , hr	h_a , n. mi.	h_p , n. mi.	Period, hr	i , deg	Ω , deg	ω , deg
1	5/11/22.08	-61.23	260.33	260.33	1.571	29.16	13.82	--
2	5/6/22.08	-61.23	260.33	260.33	1.571	29.16	84.41	--
3	4/26/22.75	-61.23	260.33	260.33	1.571	29.16	41.42	--
4	4/11/22.55	-61.23	260.33	260.33	1.571	29.16	143.06	--
1	5/1/21.85	-62.57	427.36	100.00	1.573	29.16	7.56	128.92
2	5/1/21.60	-62.25	427.36	100.00	1.573	29.16	81.16	36.67
3	5/6/21.85	-62.56	427.36	100.00	1.573	29.16	10.49	132.34
4	4/1/22.55	-62.20	427.36	100.00	1.573	29.16	155.31	53.80

(b) Final orbit before plane change

1	5/13/20.10	-15.18	65 264	260.33	48.0	29.16	13.31	123.19
2	5/8/21.01	-14.21	65 264	260.33	48.0	29.16	83.90	78.33
3	4/28/22.55	-13.07	65 264	260.33	48.0	29.16	40.92	102.26
4	4/13/20.80	-14.99	65 264	260.33	48.0	29.16	142.56	25.07
1	5/3/21.08	-14.27	65 423	100.83	48.0	29.16	7.04	135.55
2	5/3/21.85	-14.05	65 389	135.49	48.0	29.16	80.63	75.87
3	5/7/21.85	-13.86	65 422	102.21	48.0	29.16	9.96	123.80
4	4/3/21.49	-13.84	65 382	142.72	48.0	29.16	154.79	12.38

(c) Final orbit after plane change (just prior to final impulse)

1	5/14/11.24	0	65 264	260.33	48.0	41.66	-5.03	138.29
2	5/9/11.26	0	65 264	260.33	48.0	30.38	99.66	64.65
3	4/29/11.64	0	65 264	260.33	48.0	43.64	81.85	129.07
4	4/14/11.78	0	65 264	260.33	48.0	27.40	139.91	27.43
1	5/4/12.35	0	65 423	100.83	48.0	36.31	-1.11	142.41
2	5/4/11.88	0	65 389	135.49	48.0	29.92	90.59	67.23
3	5/9/11.65	0	65 422	102.20	48.0	46.25	-11.83	141.31
4	4/4/11.33	0	65 382	142.72	48.0	19.20	142.71	23.49

(d) Departure hyperbola

V_∞ data case no.	V_∞ , fps	Right ascension, ^b deg	Declination, ^c deg	i , deg	Ω , deg	ω , deg	ΔV_E , fps	ΔV_M , fps
1	10 475	-73.30	-39.57	41.66	-5.03	138.29	13 310	8 845
2	9 001	-47.37	-17.69	30.38	99.66	64.65	12 620	10 193
3	9 009	-66.33	-42.58	43.64	81.85	129.07	13 240	9 180
4	9 941	-42.62	1.31	27.40	139.91	27.43	12 675	10 429
1	9 195	-61.37	-32.54	36.31	-1.11	142.41	13 175	8 664
2	8 698	-52.63	-19.01	29.92	90.59	67.23	12 150	10 249
3	9 987	-72.18	-42.23	46.25	-11.83	141.31	13 000	8 778
4	10 481	-44.65	2.55	19.20	142.71	23.49	12 860	10 287

^a1986^bRight ascension of departure asymptote.^cDeclination of departure asymptote.

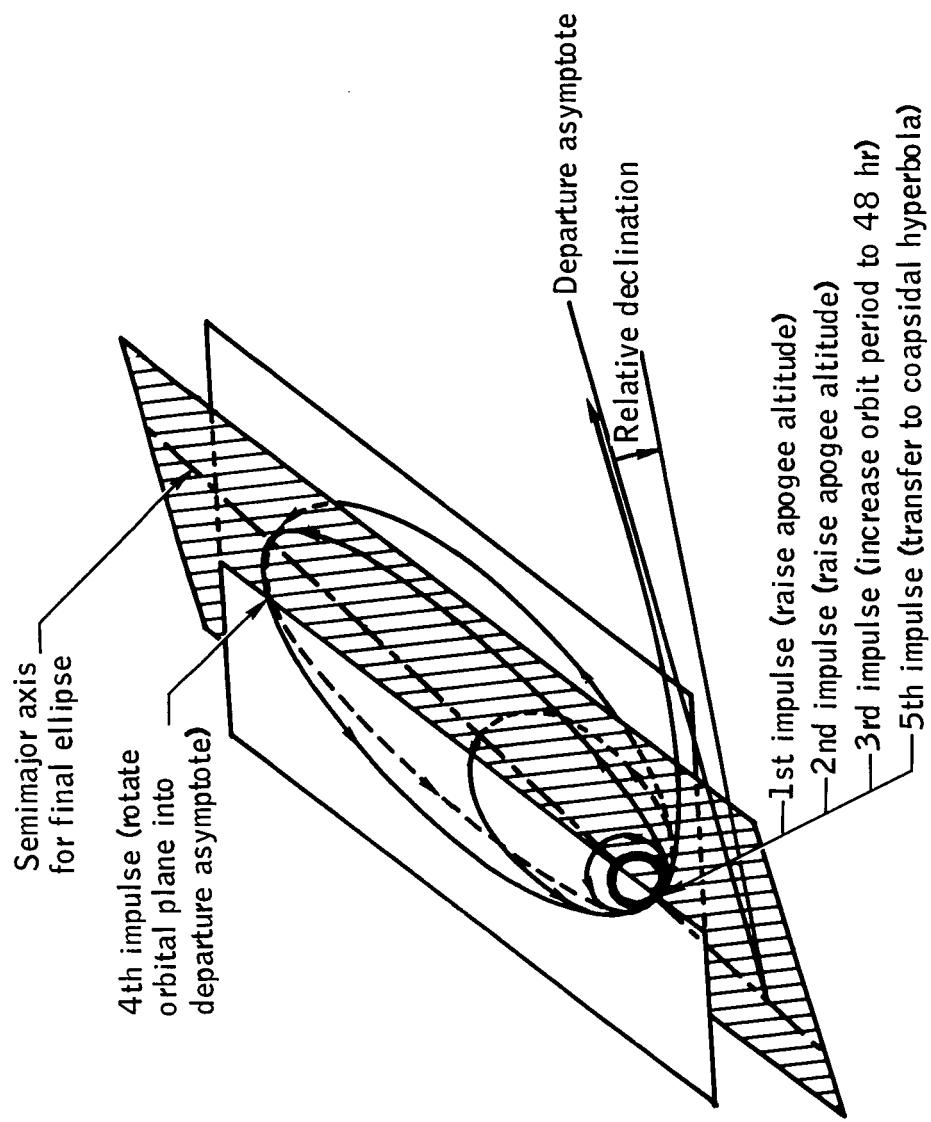


Figure 1. - Geometry of the five-impulse departure technique.

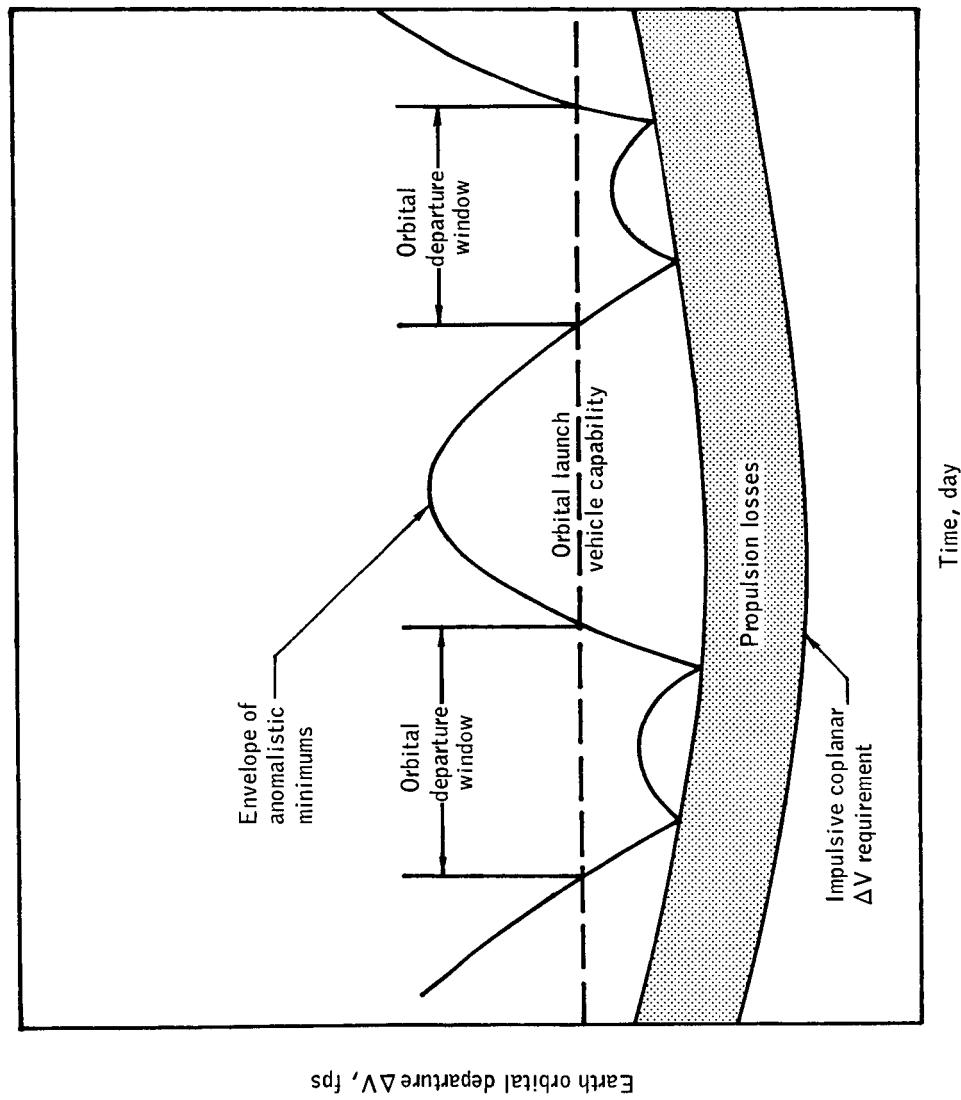


Figure 2.- Definition of orbital-departure window.

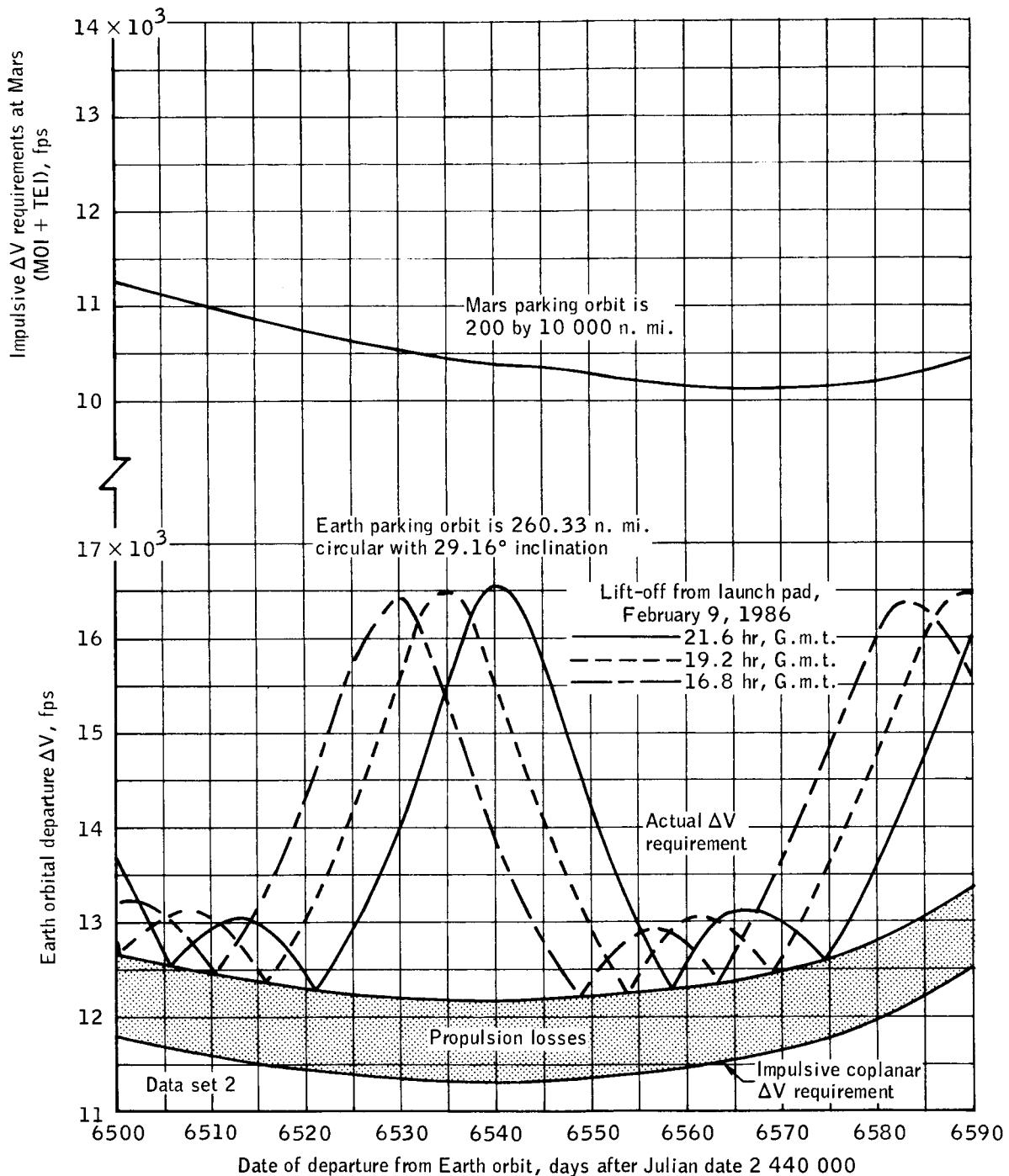


Figure 3.- Effect of pad lift-off time on nodal window for circular assembly orbit (three-impulse trans-Mars trajectories with Earth departure asymptotes in ecliptic plane).

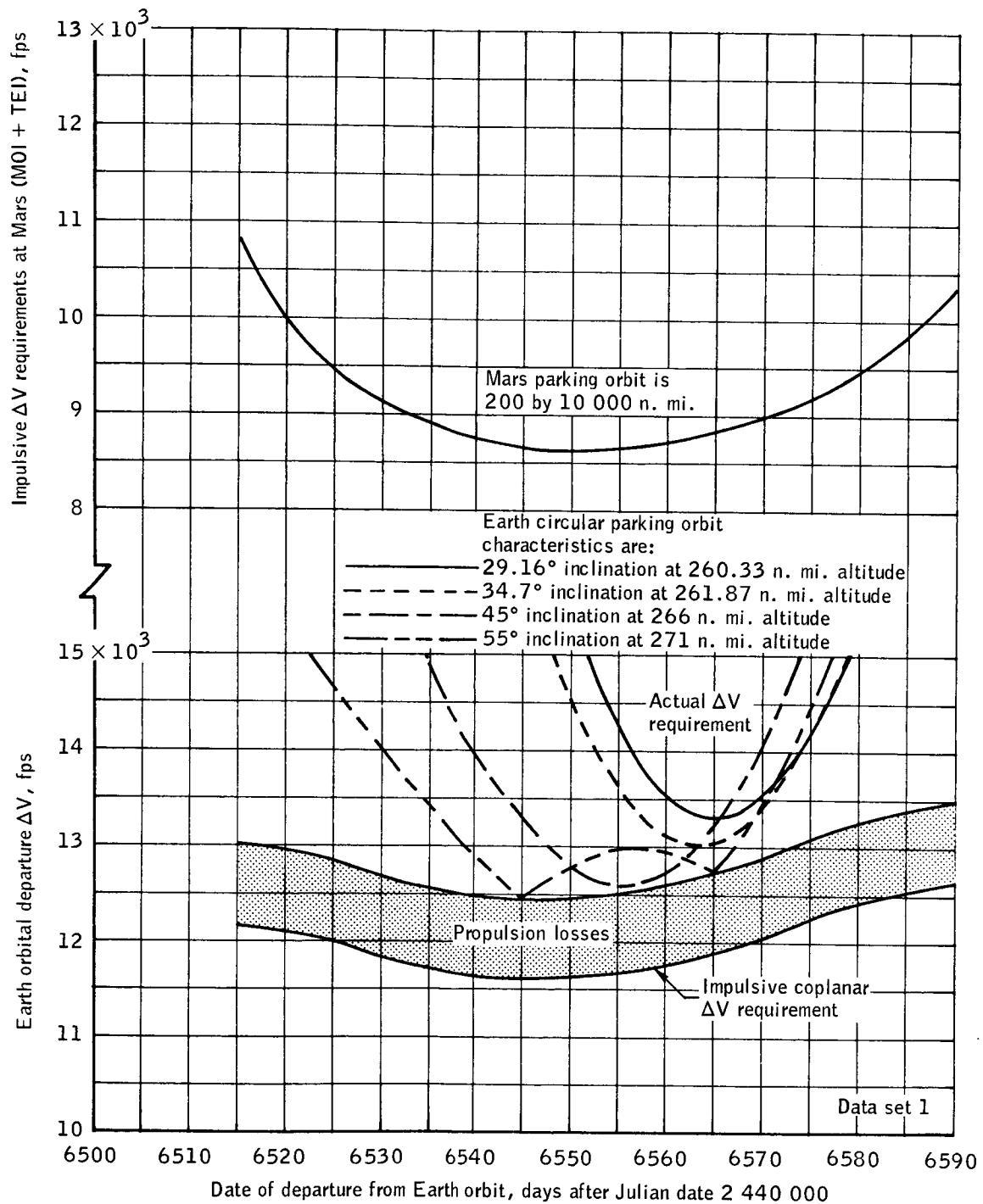


Figure 4.- ΔV requirements for 1986 Mars conjunction class mission using two-impulse trans-Mars trajectories with transfer angles less than 180° (circular assembly orbit).

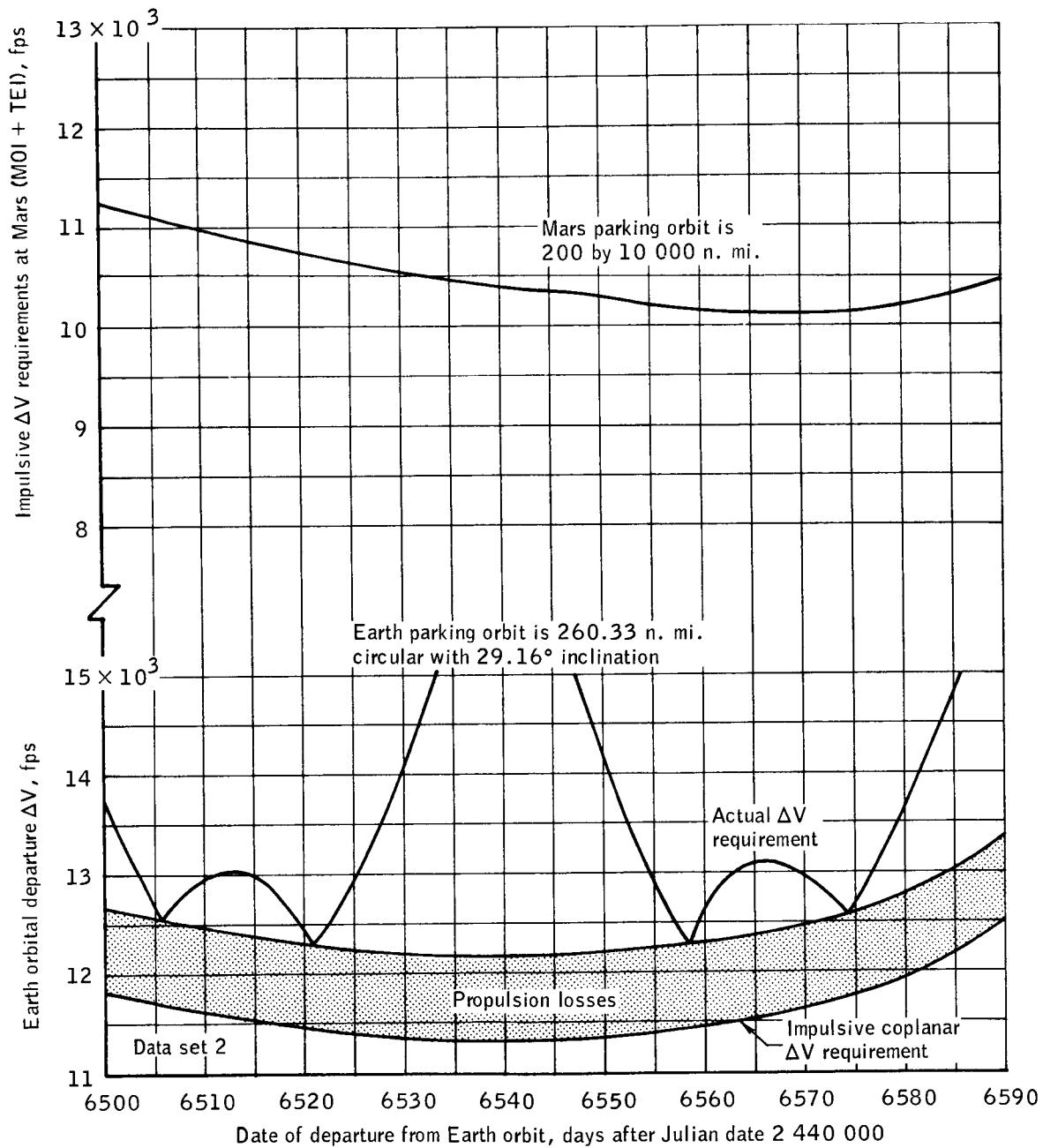


Figure 5.- ΔV requirements for 1986 Mars conjunction class mission using three-impulse trans-Mars trajectories with Earth departure asymptotes in ecliptic plane (circular assembly orbit).

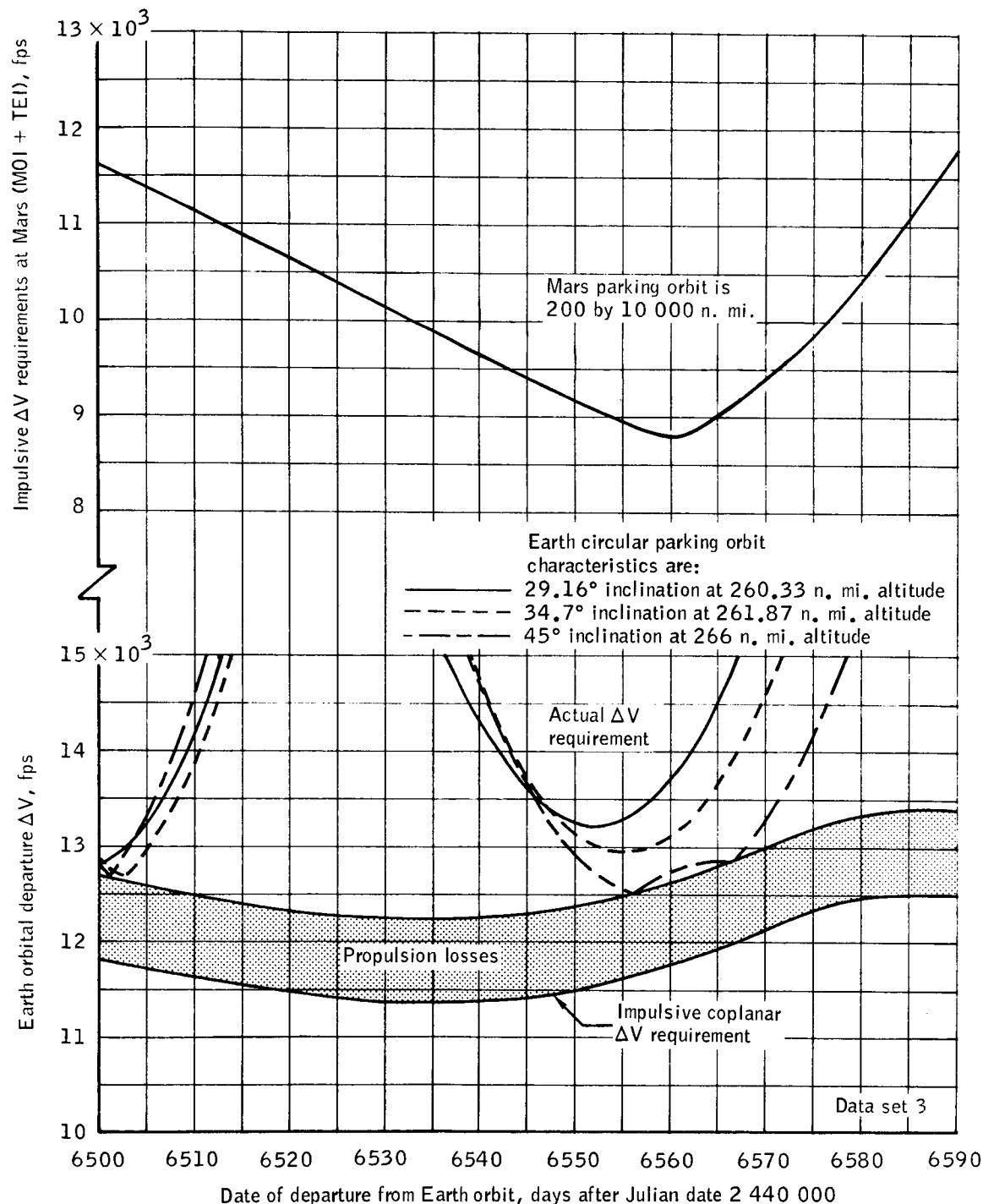


Figure 6.- ΔV requirements for 1986 Mars conjunction class mission using three-impulse trans-Mars trajectories with Mars arrival asymptotes in the Mars orbit plane (circular assembly orbit).

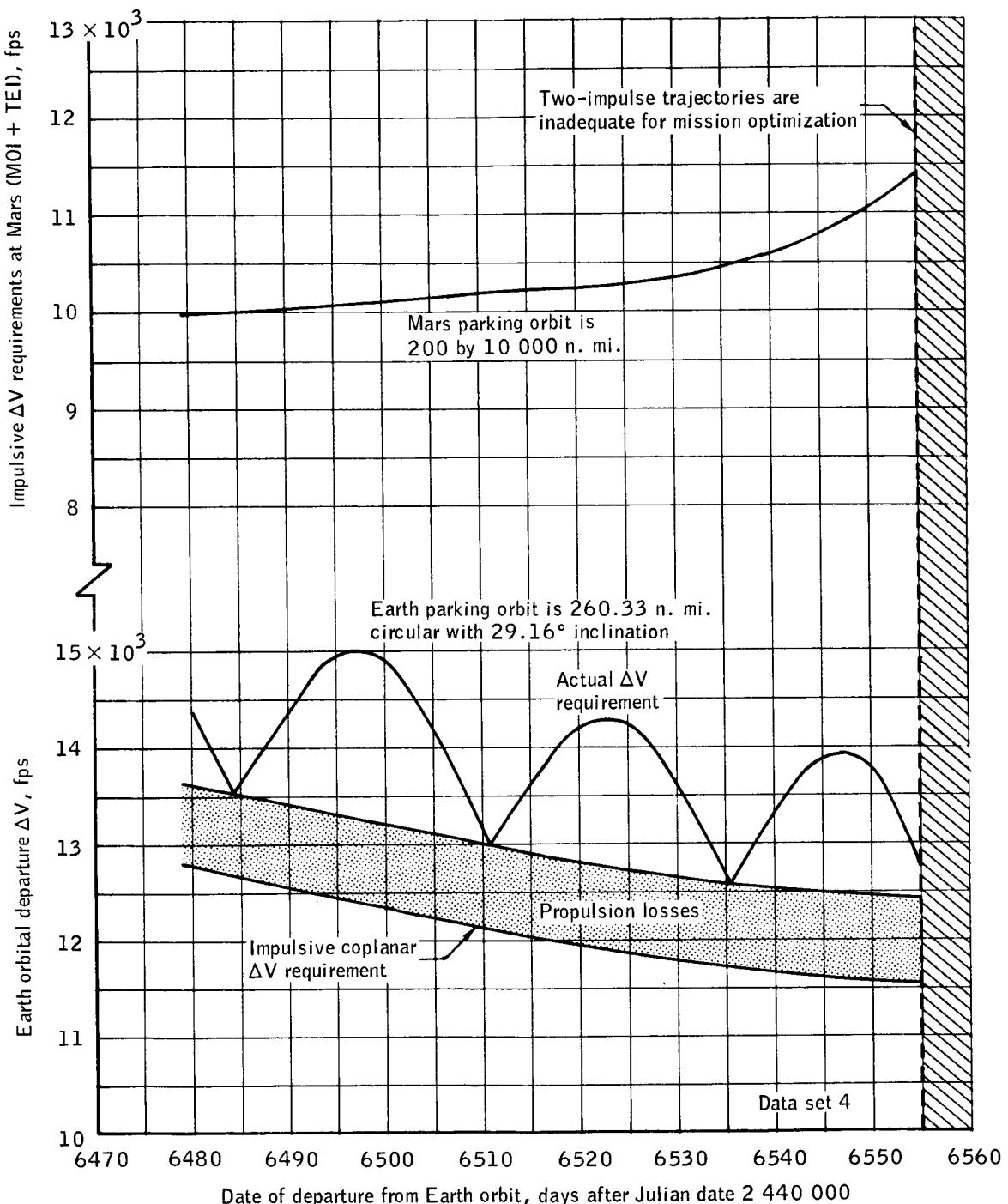


Figure 7.- ΔV requirements for 1986 Mars conjunction class mission using two-impulse trans-Mars trajectories with transfer angles greater than 180° (circular assembly orbit).

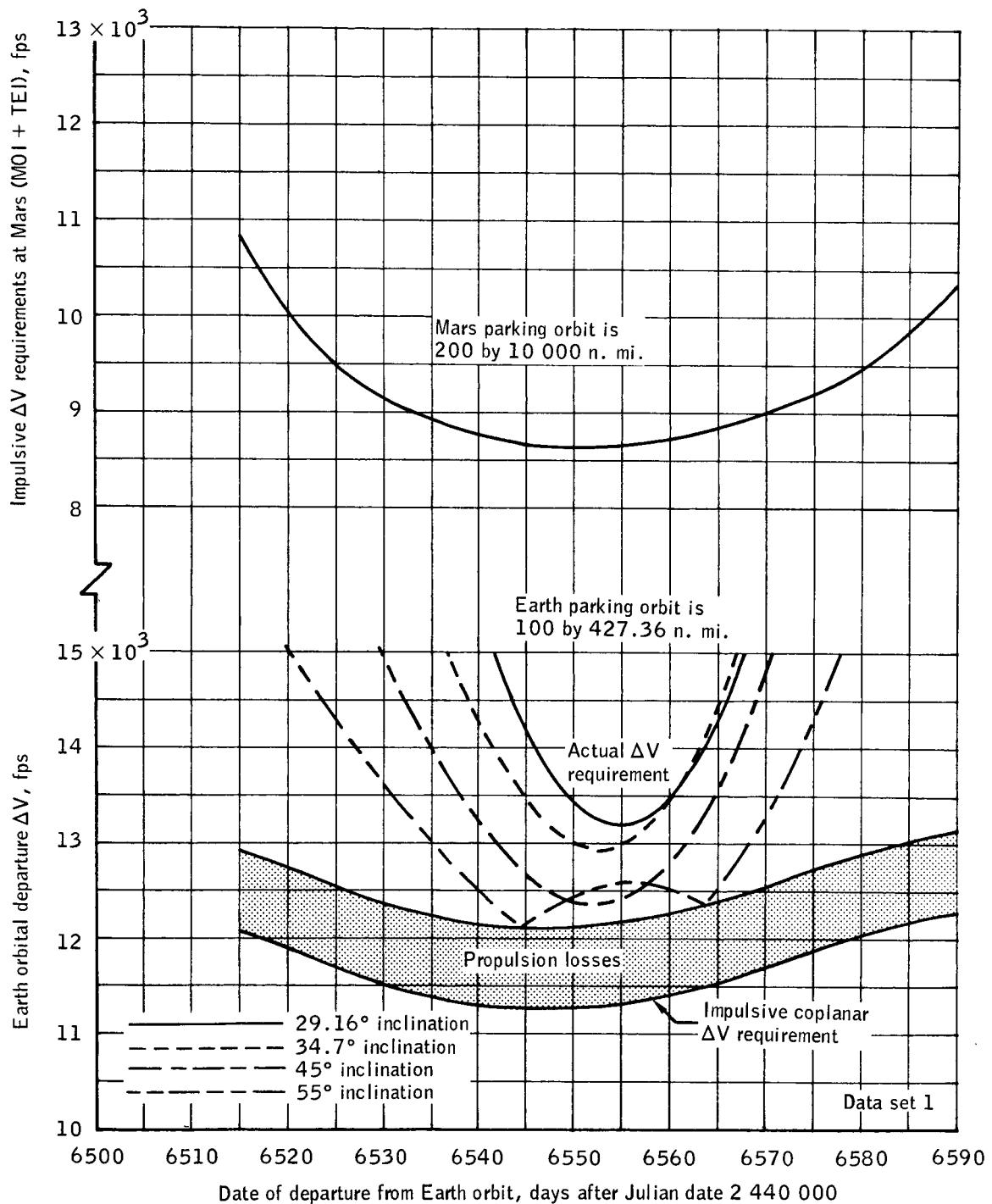


Figure 8.- ΔV requirements for 1986 Mars conjunction class mission using two-impulse trans-Mars trajectories with transfer angles less than 180° (elliptical assembly orbit).

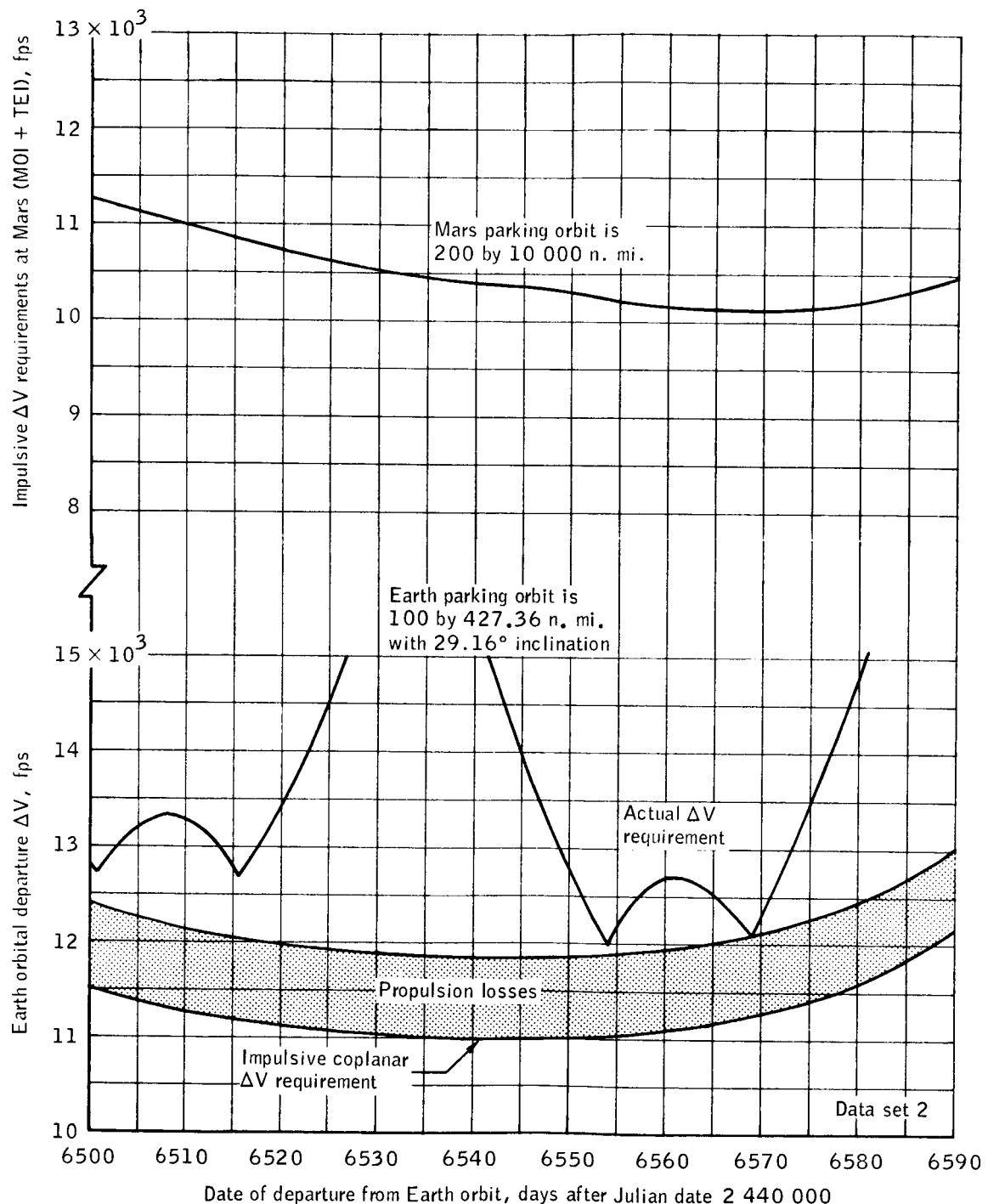


Figure 9. - ΔV requirements for 1986 Mars conjunction class mission using three-impulse trans-Mars trajectories with Earth departure asymptotes in ecliptic plane (elliptical assembly orbit).

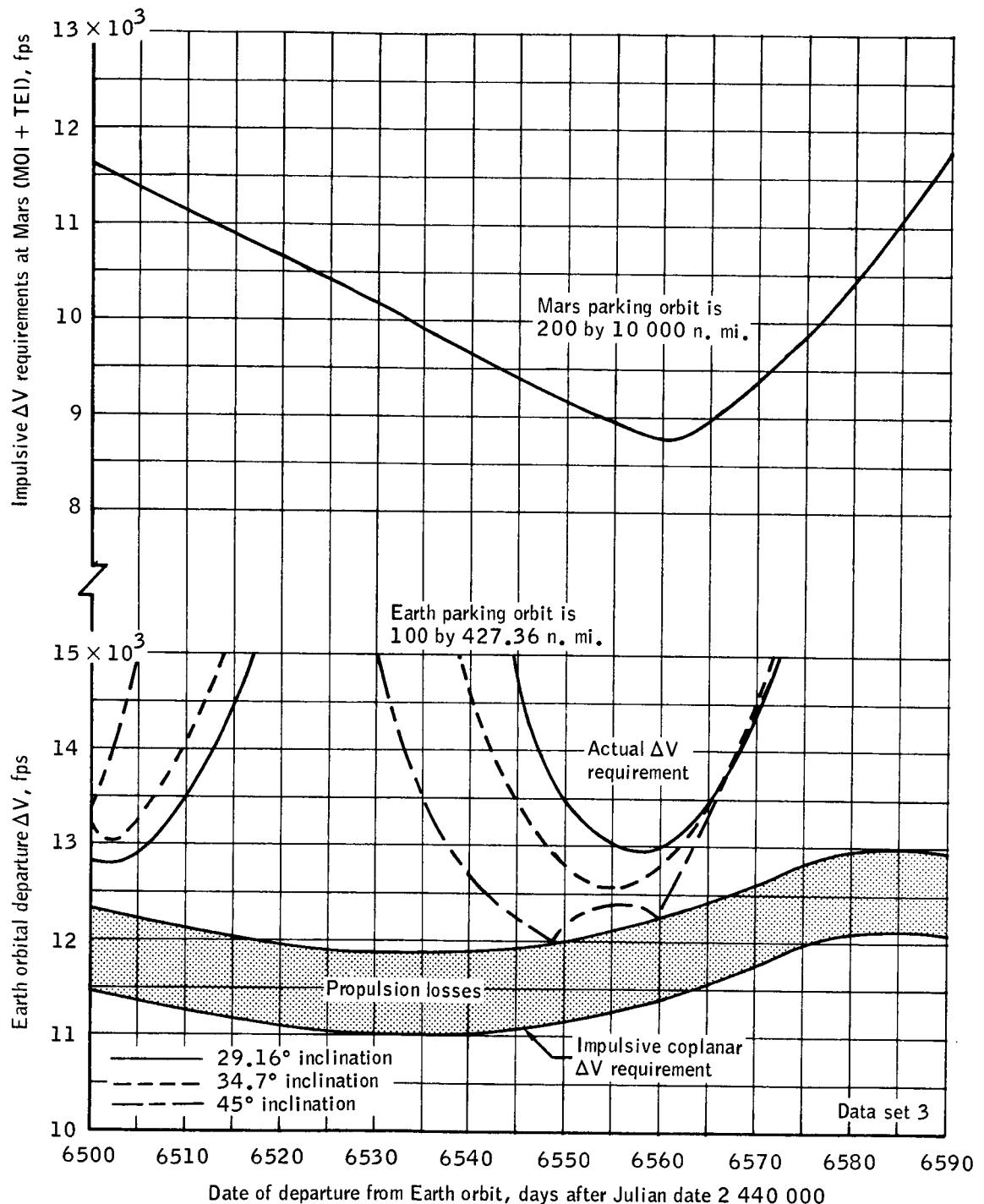


Figure 10.- ΔV requirements for 1986 Mars conjunction class mission using three-impulse trans-Mars trajectories with Mars arrival asymptotes in the Mars orbit plane (elliptical assembly orbit).

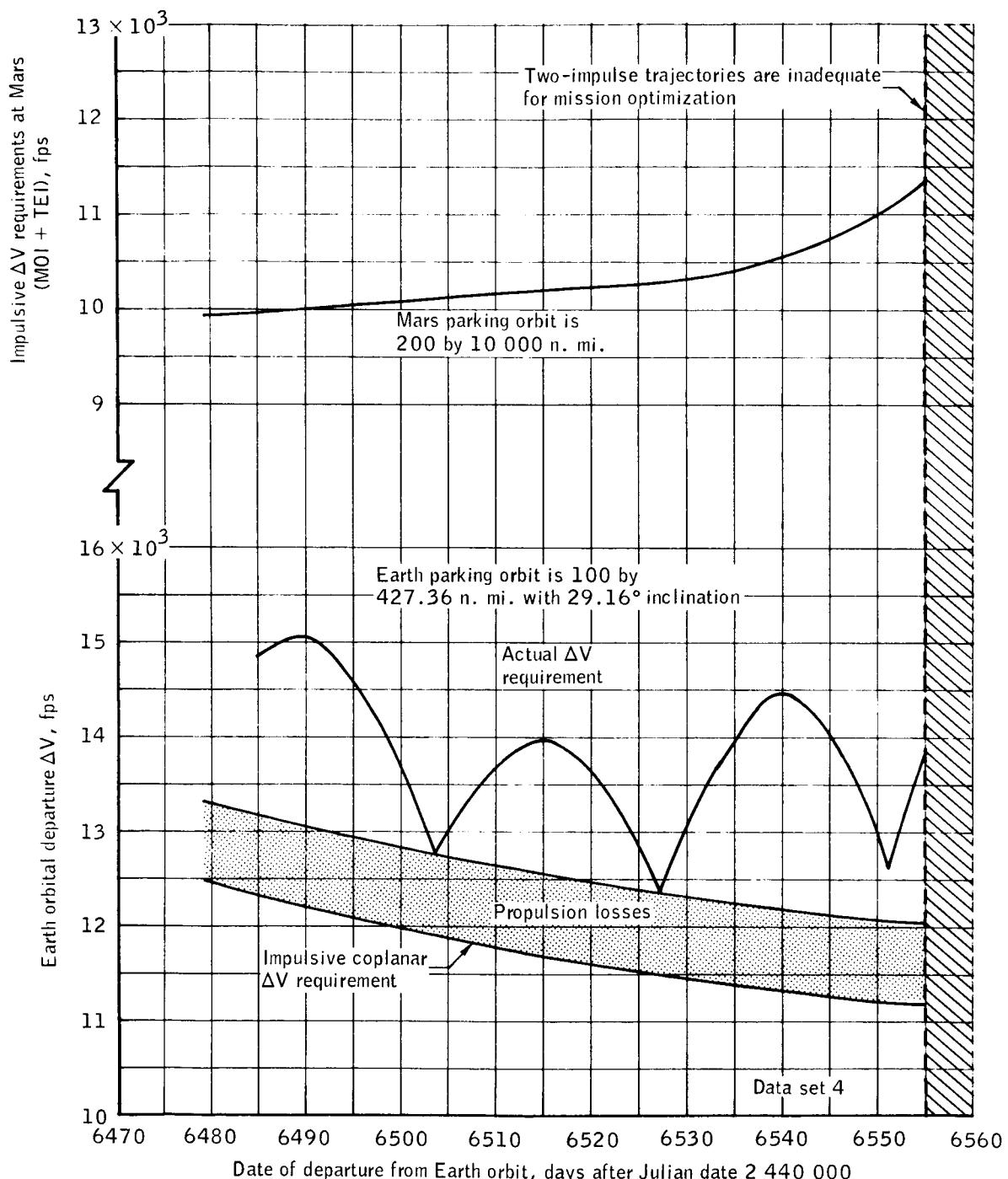


Figure 11.- ΔV requirements for 1986 Mars conjunction class mission using two-impulse trans-Mars trajectories with transfer angles greater than 180° (elliptical assembly orbit).

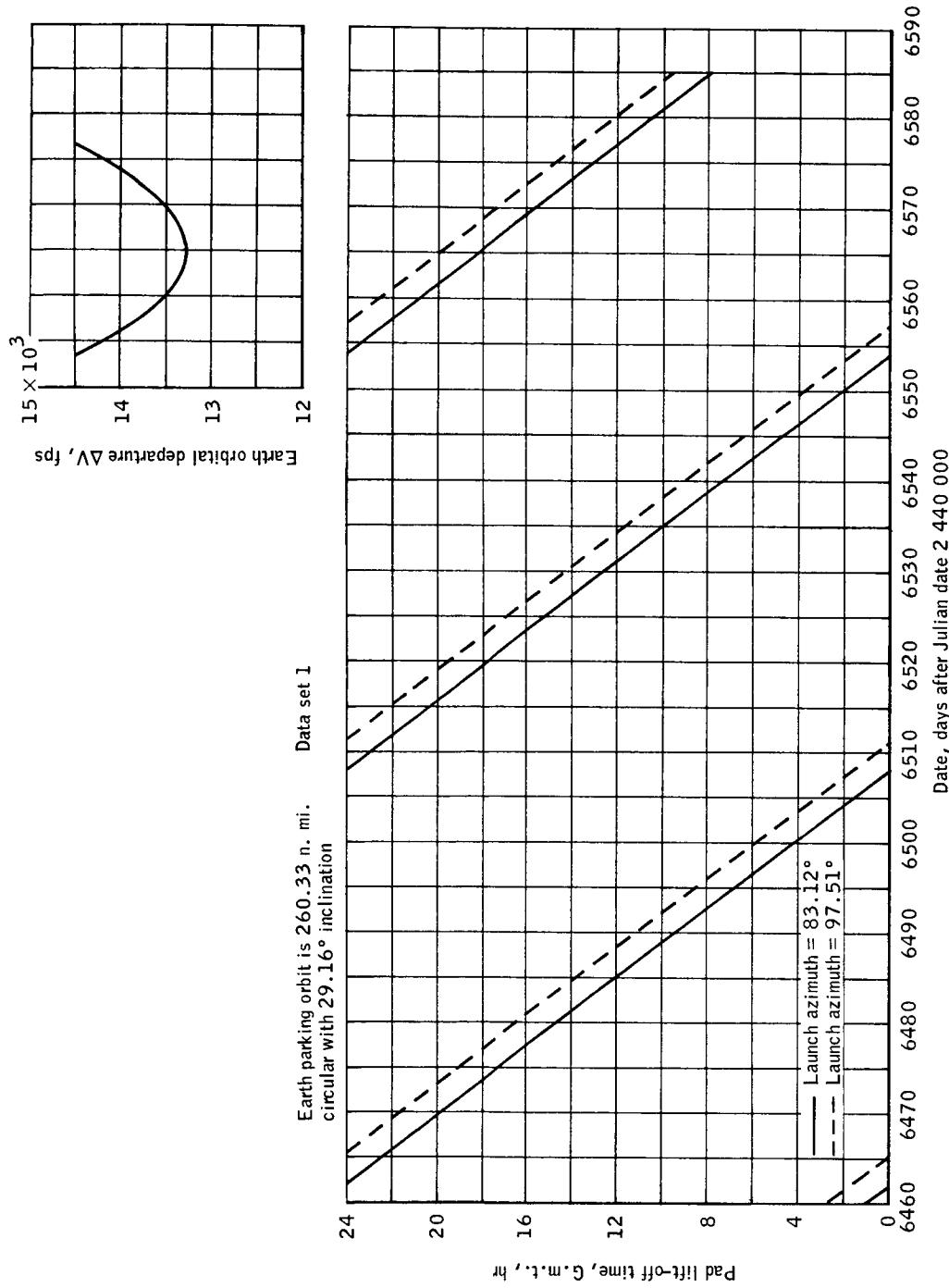


Figure 12.- Launch schedule for 1986 Mars conjunction class mission using two-impulse trans-Mars trajectories with transfer angles less than 180° (circular assembly orbit).

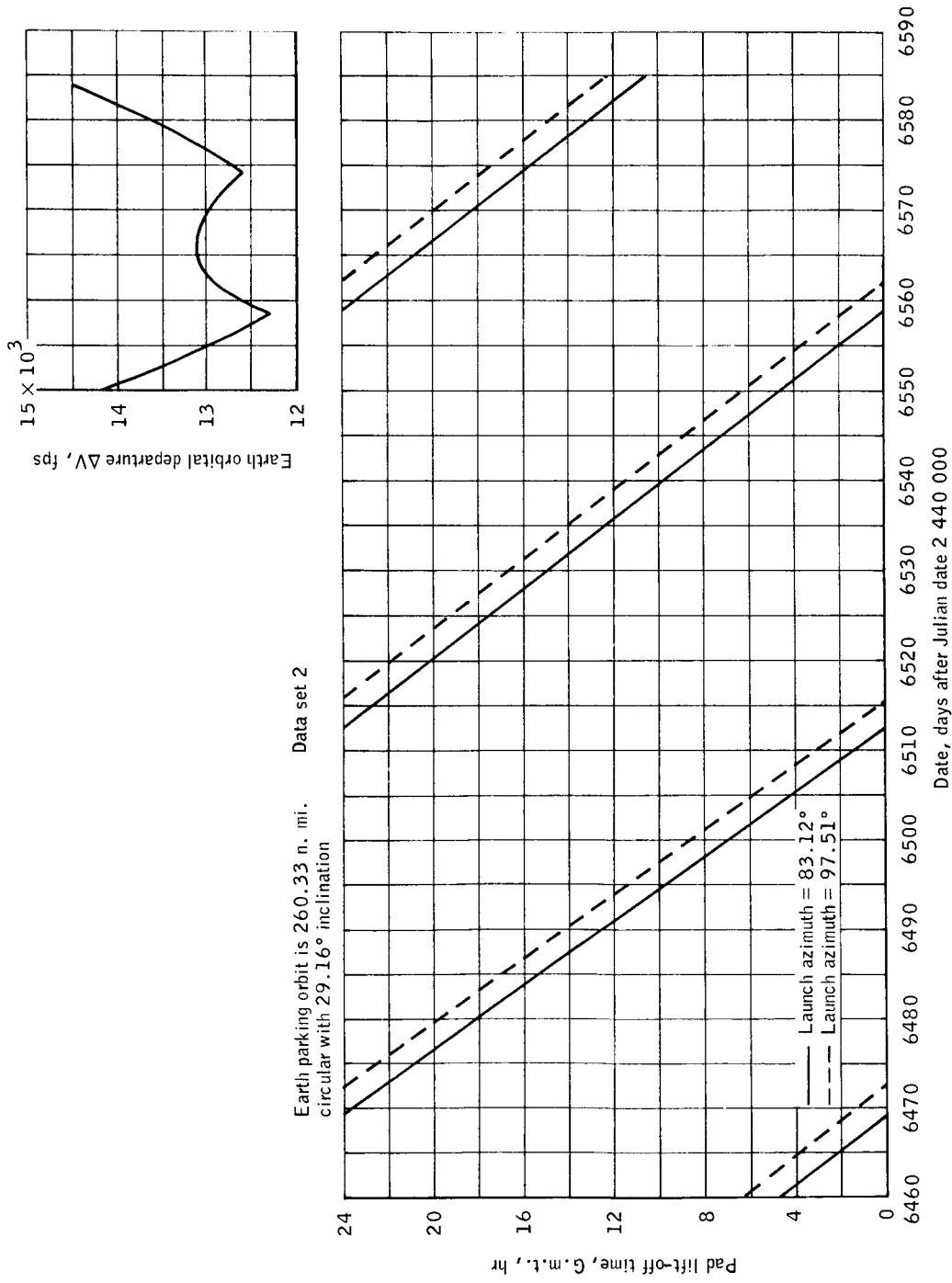


Figure 13.- Launch schedule for 1986 Mars conjunction class mission using three-impulse trans-Mars trajectories with Earth departure asymptotes in ecliptic plane (circular assembly orbit).

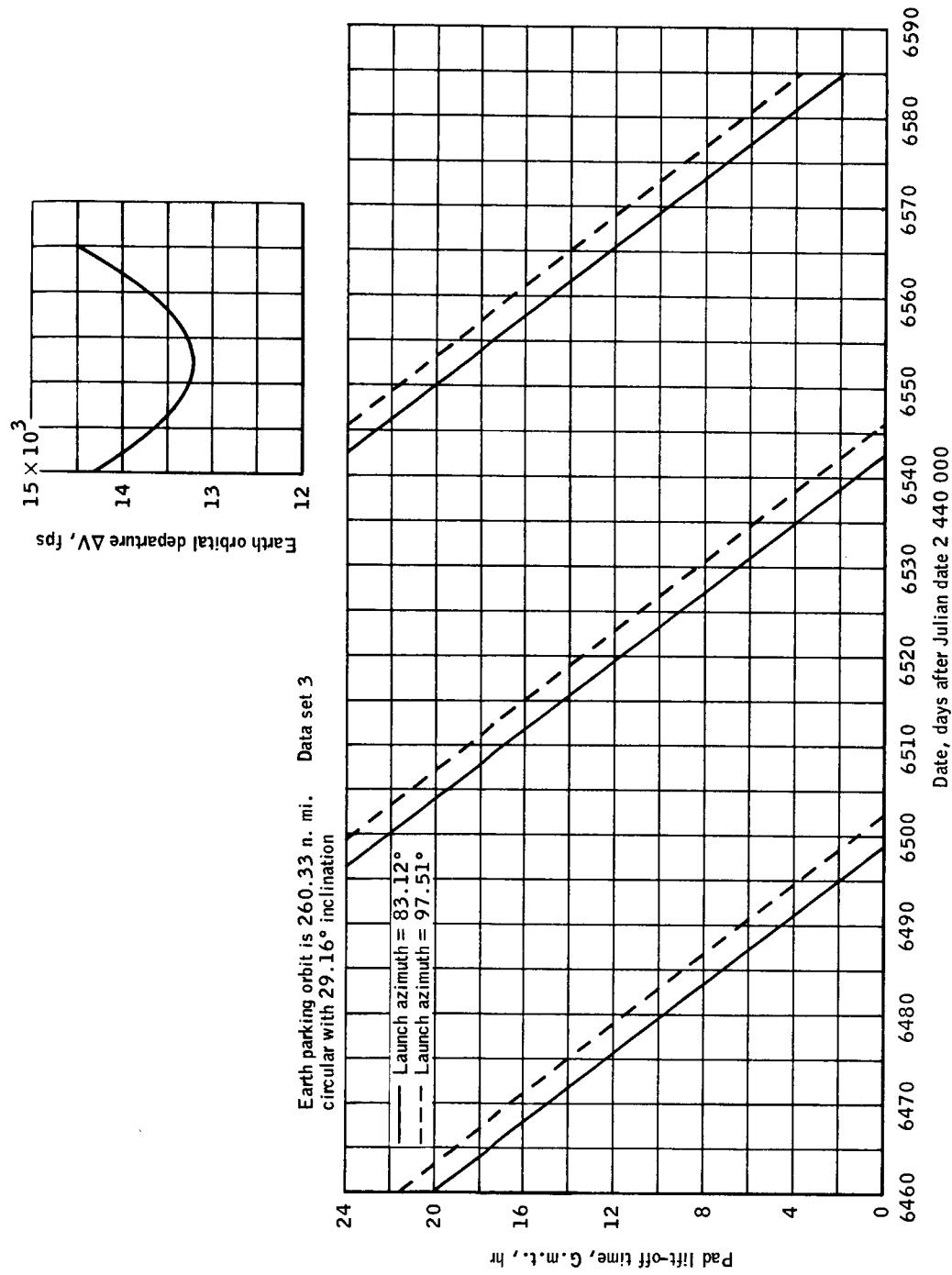


Figure 14.—Launch schedule for 1986 Mars conjunction class mission using three-impulse trans-Mars trajectories with Mars arrival asymptotes in the Mars orbit plane (circular assembly orbit).

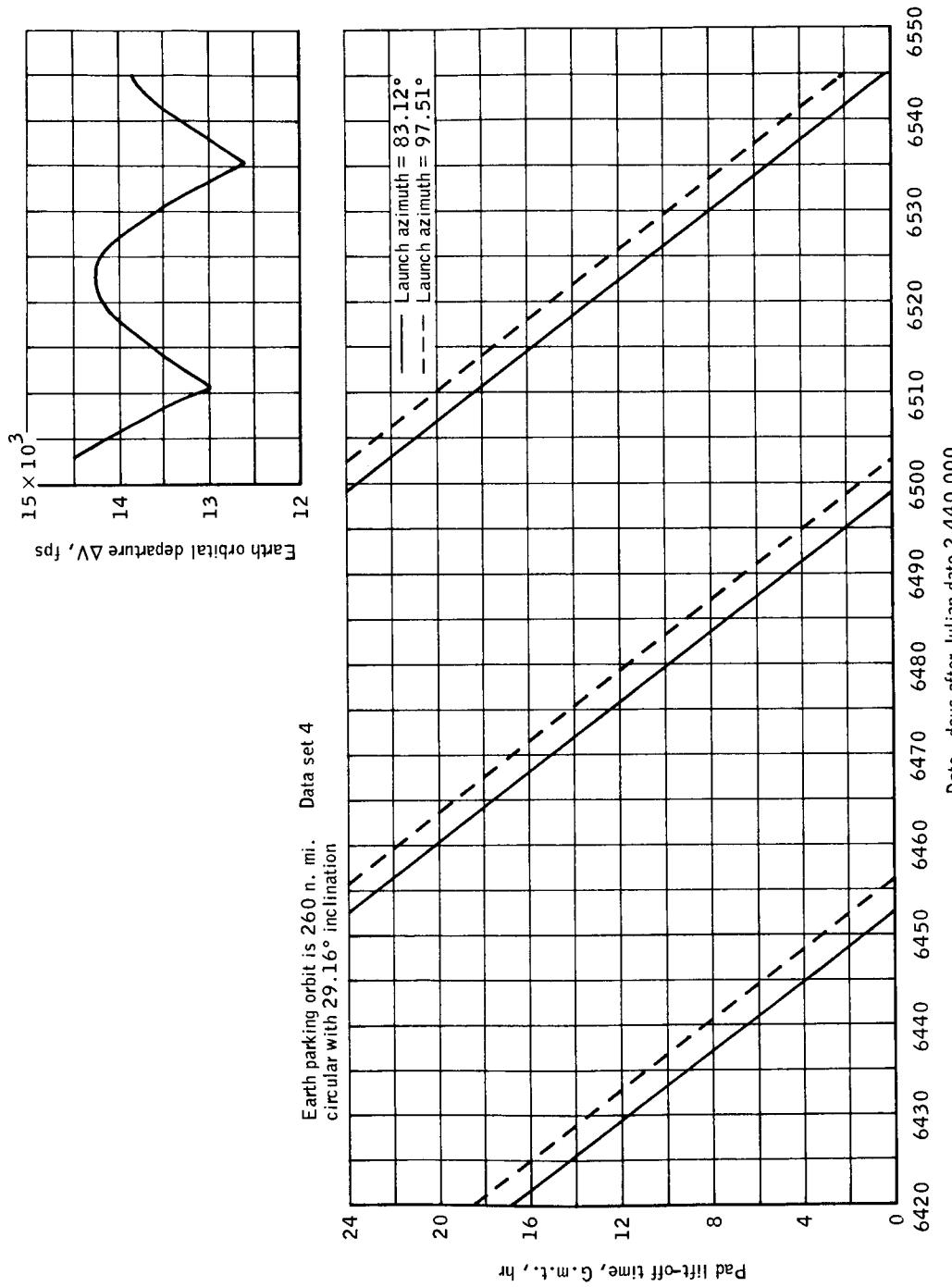


Figure 15. - Launch schedule for 1986 Mars conjunction class mission using two-impulse trans-Mars trajectories with transfer angles greater than 180° (circular assembly orbit).

APPENDIX

EARTH DEPARTURE V_∞ VECTORS

APPENDIX

EARTH DEPARTURE V_∞ VECTORS

The magnitude, right ascension, and declination of the V_∞ vectors for four different energy windows are listed in tables A-I through A-IV for the 1986 Mars conjunction class mission. The Julian data of departure is also listed and corresponds to the time when the spacecraft is at periaxis of the departure hyperbola. These data were obtained from the trajectory computations required in references 3 and 4.

TABLE A-I.- EARTH DEPARTURE V_{∞} VECTORS FOR THE 1986 MARS

CONJUNCTION CLASS MISSION USING TWO-IMPULSE TRANS-MARS

TRAJECTORIES WITH TRANSFER ANGLES LESS THAN 180°

Julian date of Earth departure	V_{∞}		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 520.0	11 225	-42.354	-61.692
2 446 522.5	11 088	-42.834	-62.303
2 446 525.0	10 950	-43.315	-62.915
2 446 527.5	10 643	-46.001	-61.918
2 446 530.0	10 336	-48.687	-60.920
2 446 532.5	10 112	-51.367	-59.751
2 446 535.0	.9 887	-54.047	-58.581
2 446 537.5	.9 744	-56.575	-57.218
2 446 540.0	.9 600	-59.104	-55.854
2 446 542.5	.9 537	-61.342	-54.317
2 446 545.0	.9 475	-63.580	-52.779
2 446 547.5	.9 491	-65.430	-51.123
2 446 550.0	.9 507	-67.281	-49.466
2 446 552.5	.9 599	-68.701	-47.765
2 446 555.0	.9 691	-70.122	-46.465
2 446 557.5	.9 854	-71.115	-44.396
2 446 560.0	10 017	-72.108	-42.728
2 446 562.5	10 246	-72.704	-41.151

TABLE A-I.- EARTH DEPARTURE V_{∞} VECTORS FOR THE 1986 MARS
 CONJUNCTION CLASS MISSION USING TWO-IMPULSE TRANS-MARS
 TRAJECTORIES WITH TRANSFER ANGLES LESS THAN 180° - Concluded

Julian date of Earth departure	V_{∞}		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 565.0	10 475	-73.301	-39.574
2 446 567.5	10 763	-73.546	-38.127
2 446 570.0	11 050	-73.791	-36.680
2 446 572.5	11 391	-73.733	-35.378
2 446 575.0	11 733	-73.674	-34.077
2 446 577.5	11 996	-72.304	-32.597
2 446 580.0	12 259	-70.934	-31.118
2 446 582.5	12 406	-68.394	-29.097
2 446 585.0	12 552	-65.855	-27.076
2 446 587.5	12 707	-63.365	-24.693
2 446 590.0	12 862	-60.876	-22.310

TABLE A-II.- EARTH DEPARTURE V_∞ VECTORS FOR THE 1986 MARS
 CONJUNCTION CLASS MISSION USING THREE-IMPULSE TRANS-MARS
 TRAJECTORIES WITH EARTH DEPARTURE ASYMPTOTES IN THE ECLIPTIC PLANE

Julian date of Earth departure	V_∞		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 500.0	10 413	-52.715	-19.033
2 446 502.5	10 147	-52.425	-18.965
2 446 505.0	9 886	-52.135	-18.896
2 446 507.5	9 714	-51.498	-18.742
2 446 510.0	9 548	-50.862	-18.588
2 446 512.5	9 398	-50.385	-18.469
2 446 515.0	9 248	-49.909	-18.351
2 446 517.5	9 033	-50.428	-18.480
2 446 520.0	8 818	-50.946	-18.609
2 446 522.5	8 792	-49.974	-18.364
2 446 525.0	8 766	-49.001	-18.120
2 446 527.5	8 604	-50.078	-18.390
2 446 530.0	8 441	-51.155	-18.660
2 446 532.5	8 391	-51.438	-18.728
2 446 535.0	8 340	-51.721	-18.797
2 446 537.5	8 324	-52.124	-18.893
2 446 540.0	8 307	-52.528	-18.989
2 446 542.5	8 328	-53.105	-19.103

TABLE A-II.-- EARTH DEPARTURE V_∞ VECTORS FOR THE 1986 MARS

CONJUNCTION CLASS MISSION USING THREE-IMPULSE TRANS-MARS

TRAJECTORIES WITH EARTH DEPARTURE ASYMPTOTES IN THE ECLIPTIC PLANE

Concluded

Julian date of Earth departure	V_∞		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 545.0	8 348	-53.503	-19.216
2 446 547.5	8 407	-54.031	-19.336
2 446 550.0	8 466	-54.559	-19.456
2 446 552.5	8 582	-53.592	-19.234
2 446 555.0	8 698	-52.625	-19.012
2 446 557.5	8 850	-49.996	-18.352
2 446 560.0	9 001	-47.367	-17.692
2 446 562.5	9 138	-46.185	-17.369
2 446 565.0	9 276	-45.004	-17.046
2 446 567.5	9 432	-46.890	-17.554
2 446 570.0	9 588	-48.776	-18.062
2 446 572.5	9 837	-50.495	-18.488
2 446 575.0	10 086	-52.214	-18.915
2 446 577.5	11 025	-53.664	-19.247
2 446 580.0	10 763	-55.115	-19.579
2 446 582.5	11 185	-56.240	-19.819
2 446 585.0	11 607	-57.365	-20.059
2 446 587.5	12 108	-58.148	-20.217
2 446 590.0	12 608	-58.931	-20.374

TABLE A-III.- EARTH DEPARTURE \vec{V}_∞ VECTORS FOR THE 1986 MARS CONJUNCTION CLASS MISSION USING THREE-IMPULSE TRANS-MARS TRAJECTORIES WITH MARS ARRIVAL ASYMPTOTES IN THE MARS ORBIT PLANE

Julian date of Earth departure	\vec{V}_∞		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 500.0	10 272	-51.738	-30.069
2 446 502.5	10 042	-51.327	-30.602
2 446 505.0	9 811	-50.915	-31.136
2 446 507.5	9 656.0	-50.181	-31.771
2 446 510.0	9 501	-49.447	-32.405
2 446 512.5	9 309	-49.627	-33.119
2 446 515.0	9 117	-49.806	-33.833
2 446 517.5	8 958	-50.372	-34.628
2 446 520.0	8 798	-50.937	-35.423
2 446 522.5	8 717	-51.074	-36.198
2 446 525.0	8 635	-51.212	-36.973
2 446 527.5	8 553	-52.578	-37.815
2 446 530.0	8 471	-53.944	-38.657
2 446 532.5	8 467	-54.664	-39.333
2 446 535.0	8 464	-55.384	-40.009
2 446 537.5	8 489	-57.459	-40.665
2 446 540.0	8 514	-59.534	-41.326
2 446 542.5	8 611	-61.825	-41.770

TABLE A-III.- EARTH DEPARTURE \vec{V}_∞ VECTORS FOR THE 1986 MARS
 CONJUNCTION CLASS MISSION USING THREE-IMPULSE TRANS-
 MARS TRAJECTORIES WITH MARS ARRIVAL ASYMPTOTES
 IN THE MARS ORBIT PLANE - Concluded

Julian date of Earth departure	\vec{V}_∞		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 545.0	8 708	-64.116	-42.220
2 446 547.5	8 858	-65.222	-42.401
2 446 550.0	9 009	-66.328	-42.582
2 446 552.5	9 242	-68.532	-42.590
2 446 555.0	9 476	-70.736	-42.598
2 446 557.5	9 732	-71.459	-42.416
2 446 560.0	9 989	-72.182	-42.233
2 446 562.5	10 287	-72.606	-41.920
2 446 565.0	10 586	-73.030	-41.607
2 446 567.5	10 925	-73.155	-41.196
2 446 570.0	11 263	-73.280	-40.785
2 446 572.5	11 638	-73.125	-40.304
2 446 575.0	12 013	-72.971	-39.823
2 446 577.5	12 193	-70.176	-39.214
2 446 580.0	12 373	-67.381	-38.605
2 446 582.5	12 423	-63.085	-37.676
2 446 585.0	12 473	-58.790	-36.747
2 446 587.5	12 405	-53.052	-35.222
2 446 590.0	12 337	-47.315	-33.698

TABLE A-IV.- EARTH DEPARTURE \vec{V}_∞ VECTORS FOR THE 1986
 MARS CONJUNCTION CLASS MISSION USING TWO-IMPULSE
 TRANS-MARS TRAJECTORIES WITH TRANSFER ANGLES
 GREATER THAN 180°

Julian date of Earth departure	\vec{V}_∞		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 485.34	13 012	-61.272	1.628
2 446 487.84	12 841	-60.059	2.064
2 446 490.34	12 671	-58.846	2.500
2 446 492.84	12 504	-57.686	2.859
2 446 495.34	12 337	-56.526	3.218
2 446 497.84	12 174	-55.422	3.498
2 446 550.34	12 010	-54.317	3.778
2 446 502.84	11 849	-53.234	3.901
2 446 505.34	11 687	-52.151	4.023
2 446 507.84	11 529	-51.119	4.039
2 446 510.34	11 370	-50.087	4.055
2 446 512.84	11 215	-49.101	3.936
2 446 515.34	11 059	-48.115	3.818
2 446 517.84	10 907	-47.181	3.553
2 446 520.34	10 755	-46.247	3.289
2 446 522.66	10 618	-45.447	2.921
2 446 525.00	10 481	-44.647	2.554

TABLE A-IV.- EARTH DEPARTURE \vec{V}_∞ VECTORS FOR THE 1986
 MARS CONJUNCTION CLASS MISSION USING TWO-IMPULSE
 TRANS-MARS TRAJECTORIES WITH TRANSFER ANGLES
 GREATER THAN 180° - Concluded

Julian date of Earth departure	\vec{V}_∞		
	Magnitude, fps	Right ascension, deg	Declination, deg
2 446 527.50	10 341	-44.105	2.361
2 446 530.00	10 203	-43.563	2.167
2 446 532.50	10 072	-43.092	1.740
2 446 535.00	9 941	-42.622	1.313
2 446 537.50	9 820	-42.193	0.557
2 446 540.00	9 699	-41.764	-0.199
2 446 542.50	9 589	-41.319	-1.450
2 446 545.00	9 480	-40.874	-2.701
2 446 547.50	9 388	-40.291	-4.780
2 446 550.00	9 296	-39.707	-6.859
2 446 552.50	9 250	-38.680	-10.566
2 446 555.00	9 203	-37.653	-14.273

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